
Chapter 2 Migratory Behavior

Through the ages, man has greatly improved his ability to navigate in his world through the use of mechanical devices which enhance his natural perceptual capabilities. The use of these navigation aids, while new to man, is fundamental to animals and their survival. The fact is, as efficient as human navigation may seem to be in the modern era, it is amateurish and trivial when compared to the natural abilities of animals (Lockley, 1967). All animals depend on movement in their habitat for survival and thus must rely on their perceptual systems to guide this motion. Therefore, a logical focus of attention in the study of wayfinding and navigation in general will include a survey of what is known, and unknown, about animal perceptual systems, their migratory behaviors, their strengths, their weaknesses, and how it all applies to the problems of human wayfinding and navigation.

Perceptual Systems

A perceptual system involves the organization and integration of sensory attributes (Shiffman, 1982). The senses, working in unison, gather information from the world either distally or locally in an effort to form an image of the world. It is the physiological capabilities of the senses which directly affect the migratory habits of the animal. The five senses of the human, sight, hearing, touch, smell, and taste, are present in most animals with greatly varying degrees of functionality. The primary senses involved in navigation, sight, hearing, and smell, are also the senses capable of distal perception. That is, they can perceive stimuli at remote locations from the body. But throughout the evolution of man,

the effectiveness of these senses has been lessened from a lack of adequate usage. They are sharp as a child but weaken with age. It is the reasoning and analytical abilities of man which have placed him in dominion over all other animals. Realizing that man has no innate ability to navigate as many animals do, man must endeavor to understand this phenomenon in order to replicate it for himself.

Touch

The sense of touch is considered to be the earliest developed sense. It is the first sense experienced by human and animal newborns. Furthermore, its use for local navigation is fundamental to survival. This is primarily exhibited in early feeding behaviors. Animals from dolphins to dogs to humans all depend on the sense of touch at birth due to the underdevelopment of sight.

But navigation by touch is not confined to the newborn. A prominent theory of obstacle avoidance by the blind suggests that the cutaneous sense can develop sufficiently to enable a visually impaired person to accurately navigate around obstacles by sensing air currents as they are affected by the obstacles in the room (Shiffman, 1982).

Tactual maps have been in use for many years to assist the blind in navigating unfamiliar spaces. However, they cannot represent the same quantity or quality of information available in a traditional map due to the resolution constraints of touch as opposed to sight.

As early as two thousand years ago, Aristotle wrote that of all the senses, “touch was the most indispensable.” More recently, this has been supported by Allen and Vekker (1994) who suggest that the key to understanding mental images and possibly mental phenomena in general may lie in the tactile sensory system. Through its direct contact with the physical world, touch may bridge the gap between objective physical reality and subjective mental representations of physical reality.

Although it is clear that many animals including humans make use of touch for local navigation, there exists no body of evidence to support the notion that the sense of touch can be used for any long range navigation. Touch is by its very nature a local sensation requiring direct contact with the stimuli.

Taste and Smell

Taste and smell are typically discussed jointly because they are so closely tied and are collectively the only chemical senses. However, taste, like touch, is a local sensation limiting its usefulness in navigation, whereas smell is distal enabling it to be used from long range.

In many animals, other senses may be limited by the habitat or may be naturally weak making scent necessary for survival. The mother seal, unable to see in the darkness of the sea cave, will not allow her pups to feed without scent identification. This is no trivial task considering that she must identify her own from among thousands of others. This same phenomenon is found in other animals like the sheep which cannot visually identify her young after shearing but must do so by its scent. And, of course, the dog which not only uses its nose to “see” but also knows to leave its scent to mark its territory. These examples are typical of many animals to which smell is a much more dominant sense than in humans.

With highly functional and developed olfactory systems, these animals are capable of remarkable feats of long distance navigating and searching using smell as their dominant sense. The distance by which scent has proven to be effective can be as high as several miles. An example of this is the fox which can be detected by a female from several miles away. The dog, while not known for its ability to detect a scent from a great distance, can clearly distinguish different scents in a small area thus able to follow a scent trail over long distances. In fact, dogs live in a world of odors in which their discriminatory ability is so selective, they can easily locate their master from a crowd of people without vision. The olfactory system of the bird, even though not nearly its strongest, is functional to the point of being able to locate food sources from a fair distance. The albatross has large tubular nostrils which can detect the scent of their favorite oily fish food over miles of open sea.

The use of smell in navigation in these examples is clear. Most use smell in the form of a trail either to be followed or to be left behind. However, in cases such as dogs marking territory and homing birds, the scent is used as a sort of olfactory landmark. This will be discussed in more detail in Avian Migration on page 14.

Sight

As reliant as humans are on sight, many animals do not share this dependency. In fact, primitive animals do not have a visual system at all. On the other extreme, the visual system of many animals is so advanced, the human visual system pales in comparison.

What is typically found in nature is vision that has adapted to specialized purposes in different animals. Prey animals, like the rabbit, must always be on the lookout for predators. Their visual system literally allows them to see front and back simultaneously. With the eyes placed on the side of the head, the rabbit has a 360° visual field. However, the side effect of a large visual field is a lack of binocular vision. Thus, a rabbit can easily detect a predator approaching from any angle but it usually has no idea how far or near it may be. In contrast, the predator's visual system is dependent on binocular vision to accurately locate objects in space. Depth and distance information is essential. The visual field of the cat, for instance, is relatively large as compared to humans while still providing a large binocular region (See Figure 2-1).

More important to navigation is visual acuity. Many birds, in particular, have developed keen eyesight. The eagle can detect the movement of a rabbit from a mile away. Even more amazing is the vulture which can identify a motionless food source from a great distance. However, not all flying animals have developed, nor do they require, efficient eyesight for survival. The bat is able to navigate through unknown obstacles without vision. It has developed a superior auditory system which supplants its visual system.

Hearing

The concept we know today as SONAR (Sound Navigation and Ranging) has been in use by bats and other animals for thousands of years. These animals emit high pitched sounds which are then received after reflecting off of the environment. In the case of the bat, this system is so effective, it can detect small flying insects which are then caught for food. The dolphin can swim without sight through a pool with random wires crossing it without touching any of the wires. In effect, for these animals, sound has taken the role of sight.

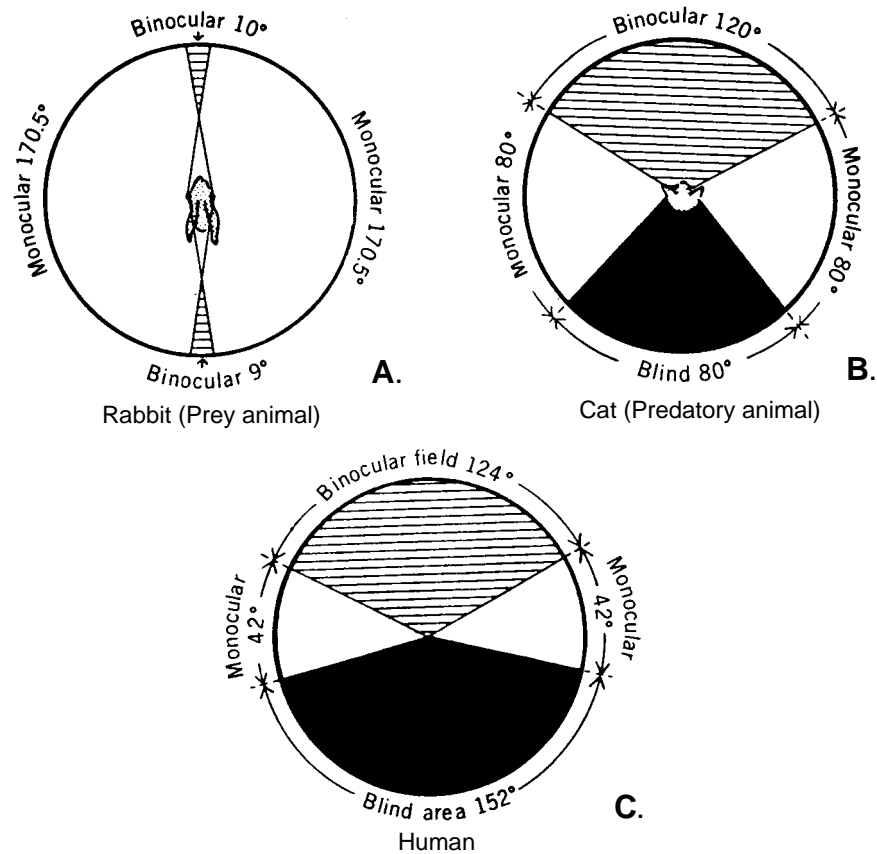


Figure 2-1 The visual field of the rabbit (A), the cat (B), and humans (C).
Reproduced from Shiffman (1982).

Realize the information necessary for these tasks. The bat determines, from the time and pitch difference in the sound emitted and received, the distance, size, and velocity of a target. Furthermore, it does this as it flies at high speeds through the environment. There is no mechanical SONAR system that can rival that of the bat. However, the bat's ability to spatially locate objects is nearly eliminated if both ears are not fully functional.

While humans cannot boast an echoing system like that of bats and dolphins, we do have some functionality in this area. We can determine the approximate size of a room we are in by listening to the echo of our voice or footsteps. We know by the changing pitch of a siren whether an ambulance is getting closer or further away. The tapping of the blind's stick tells of the size and location of obstacles. We are very sensitive to acoustics. Any

musician, before a performance, painstakingly tests and adjusts the position and volume of the amplifiers to get the desired sound quality.

Of course, most animals do not possess an innate SONAR system but still effectively make use of hearing for survival. Many predatory birds, such as the hawk, listen for the chirping sounds of smaller birds. The cry of a hawk or owl can often silence smaller birds for a time. Birds, in general, do not have the auditory range of humans. They are unable to hear sounds on either extreme of the frequency spectrum. Wolves and dogs are notorious for their audible acuity. Like most other predatory animals, they greatly rely on hearing as well as sight and smell to locate and track their prey.

To this point, discussion has been limited to the senses alone and how they are used to perform sense-specific tasks. However, no sensory system operates in isolation. All are a part of a greater whole from which an image of the world emerges. Thus we turn now to the bigger picture; how do animals perform the higher level operations of navigation as a part of the overall task of migration?

Avian Migration

Due to their miraculous feats of navigation during migration, birds have been widely studied through the years yielding many theories as to what they perceive and how they use it. Although evidence exists to support each of these theories, they mostly remain hypothetical. However, our interests lie in the more “human” forms of navigation which birds employ; primarily their use of landmarks, mental maps, and celestial navigation.

In one homing experiment, the Manx shearwaters, which nest near Stockholm, Sweden, were taken to several release sites; one as far off as Boston, Massachusetts. When released, if the sun was visible, the bird unhesitatingly flew in the correct direction of Stockholm, whereas if the weather happened to be overcast, the bird circled and eventually was either lost or returned to the release site.

Another example is the Laysan albatross of Midway Island in the Pacific. When airstrips were being built there, the albatross became a nuisance as they insisted on nesting

on runways. The solution was to banish them to Japan and the Philippines over 4,000 miles away. Fourteen out of eighteen of the birds returned. The sun was out on their release as well (Lockley, 1967).

These demonstrations have been reproduced many times to show that birds have an internal sun compass which enables them to determine their absolute orientation based on the sun's position and the time of day (Dorst, 1962; Popi & Wallraff, 1982; Schmidt-Koenig, 1979). This is the same form of navigation used by mariners for several centuries known as celestial navigation (See Marine Navigation on page 50). It has also been shown that non-migratory species are much weaker in this ability than their migratory counterparts.

Another theory suggests an ability to detect the motion of the moon and stars. This has been supported in homing experiments by night flying birds which exhibit similar abilities to orient over seemingly featureless terrain.

Beyond the speculation, the physical attributes of birds to see well, hear well, and smell well make them excellent navigators. And their ability to fly gives them a visual range far greater than land animals. Birds can migrate day or night with small birds typically flying at night to avoid predators. They are rarely troubled by bad weather conditions. They will either wait it out or fly right through it. Seldom do birds fly above 5000 feet or below 3000 feet while migrating. Typical airspeeds are between 6 and 10 m.p.h. (Wetmore, 1930).

Birds can navigate by visual, aural, or olfactory landmarks. Olfactory landmarks are typically wind dependent. Furthermore, they do not tend to make a distinction between the different sensory landmarks allowing them to function effectively when one sensory mode is limited or unusable such as when flying at night, in a noisy environment, or when the wind is in a lull. Thus vision is less dominant in birds than in humans.

Their use of landmarks suggests that birds may form mental maps. These would include information such as

- which sites offer what resources and when,

- the landmarks by which the different sites may be recognized,
- the spatial relationships of the sites, and
- the best (safest or shortest) routes to travel between them.

Other information may include topological data such as landscape gradients which offer additional information about the environment (Baker, 1984). For example, a bird can use the slope of a hill or the direction of flow of a river as a landmark.

As proficient as birds may be at navigating over large distances, their abilities are not unique. Other animals, most confined to the Earth's surface, also perform amazing feats of navigation.

Other Animal Migratory Behaviors

Monarch butterflies, along with many other insects, make an annual migration similar to that of birds. Their ability to travel hundreds or thousands of miles to a particular location requires some explanation. Urquhart (1987) suggests that Monarch butterflies use little, if any, explicit navigation methods in their travels. Their migration is lead almost entirely by instinct. Their accuracy in direction finding has been shown to be far below that of other migratory animals. However, Lockley (1967) provides evidence that many insects have the ability to perceive polarized light and to determine their location on the Earth based on its patterns. More recently, this theory has been supported by a number of experiments and has been expanded to include many insects with a compound eye structure typical of bees, wasps, and ants.

The direction finding and indicating capabilities of bees has been well documented. In particular, their behavior of indicating the direction and distance to a food source via a dance is unique in the animal world. This is especially interesting considering that their relative, the wasp, uses a landmark and dead reckoning method for the same task.

Like the migration of many insects, fish migrations also have been shown to be predominantly instinctive (McKeown, 1984; Meek, 1916; Smith, 1985). Fish migrate distances up to 10,000 kilometers for durations from two to four months at an average speed of 5 km/hr. There is no convincing evidence that fish actually navigate; rather they instinc-

tively follow environmental cues to a known location. The most famous of the fish migrators is the salmon which has been known to travel great distances from the sea to spawn in the very same tributary of the very same river in which it was spawned. They may use any of the following cues to locate their home: currents, olfactory cues, visual cues, water salinity, water temperature, solar orientation, lunar orientation, or magnetic fields.

The Ascension Island green turtles swim from the coast of Brazil over open sea to a small island in the mid-Atlantic (Gerrard, 1981). It is believed that the Gulf stream is being used as a guide. This has given rise to the *passive drift theory* which would apply to any migration which is directed by an external guide.

The primary lesson to be learned here is not in the specific triads of environmental cues, perceptual systems, and migratory behaviors of an animal but rather in the ways in which animals have adapted their behaviors to available cues. This will apply to humans in virtual worlds because since the world is malleable to the world designer's specifications, cues can be altered so as to be perceptible to humans or tools can be provided to assist users in perceiving the cues.

